CHAPTER 1

INTRODUCTION

Respiratory rate (RR) is a vital sign that provides essential insights into a person's health and well-being. Accurate and continuous monitoring of RR is critical for timely interventions, early detection of deterioration, and diagnosis of respiratory diseases. Traditional methods that require physical contact can be uncomfortable for patients, increase the risk of infections, and restrict continuous monitoring. This underscores the need for a contactless, patient-focused approach to RR measurement that maintains accuracy, comfort, and ease of use across various healthcare settings.

Radar technology, specifically Frequency-Modulated Continuous Wave (FMCW) radar, holds significant promise to address these challenges. Integrated with advanced signal processing and machine learning (ML) techniques, it enables precise RR estimation without direct patient contact. This research focuses on developing and validating a new contactless RR measurement system using 24GHz FMCW radar, signal processing, and the robust XGBoost ML algorithm. By leveraging this potential, the research proposes an innovative, contactless method for RR measurement. The subsequent sections discuss this research's rationale, theoretical background, methodology, and potential significance.

1.1 Rationale

Accurate RR measurement is essential for assessing patient health [1]. Although traditional contact-based methods involving electrodes attached to the skin are effective, they can be uncomfortable for patients, limiting the feasibility of continuous monitoring [2]. Contactless approaches, particularly those using radar technology, present a valuable alternative. This research utilizes 24GHz FMCW radar, which is noted for its ability to emit signals with linearly varying frequencies crucial for detecting subtle chest wall movements during respiration [3–6]. Advanced signal processing and ML techniques are central to building a contactless system emphasizing accuracy in RR measurements [7, 8].

The global increase in chronic respiratory diseases highlights the urgent need for precise and accessible RR monitoring [9, 10]. Healthcare systems are pressured to improve patient outcomes while managing resource constraints. Traditional contact-based methods pose challenges for continuous monitoring due to infection risks and potential patient discomfort. This ongoing discrepancy between accuracy, comfort, and usability underscores the need for a new contactless RR measurement method that addresses these challenges in all healthcare settings [11].

Accurate RR measurement is crucial for timely detecting respiratory issues, reducing the risk of adverse health events, and ensuring patient safety. The COVID-19 pandemic has underscored the importance of hygienic, uninterrupted monitoring solutions [12]. The limitations of traditional contact-based methods and the variable accuracy of existing contactless options highlight the need for improvements. Studies have demonstrated the potential of radar-based non-contact vital sign monitoring as a viable solution that prioritizes clinical accuracy, patient comfort, and adaptability to diverse healthcare requirements [8].

This thesis proposes an innovative solution combining 24GHz FMCW radar with advanced signal processing and the XGBoost machine learning algorithm. FMCW radar facilitates a contactless, patient-centered approach to RR measurement by detecting subtle physiological changes related to breathing [13, 14]. Signal processing techniques are vital for accurately interpreting complex radar data to identify respiratory patterns, while XGBoost effectively enhances precision and adaptability across different patients and settings. This approach could transform respiratory health assessment, offering a method that increases clinical accuracy and prioritizes patient comfort.

1.2 Theoretical and Conceptual Framework

Several theoretical frameworks are essential for effectively analyzing and interpreting FMCW radar data for RR estimation. Signal processing theory provides the foundation for extracting meaningful respiratory patterns from radar data [15]. Specifically, spectral analysis and filtering are crucial for isolating these patterns. Additionally, the physiological principles of respiration guide the interpretation of this data, emphasizing the need for advanced signal-processing techniques.

Machine learning, mainly supervised learning models, is a powerful tool for constructing predictive models. Regression algorithms such as Support Vector Regression (SVR), k-Nearest Neighbors (kNN), Random Forest (RF), Gradient Boosting (GB), and Extreme Gradient Boosting (XGBoost) are vital for developing these models [16]. These algorithms excel at learning complex relationships between processed radar features and ground-truth RR values, enhancing the precision of the contactless RR measurement system.

This research employs a conceptual framework integrating signal processing, physiological principles, and machine learning to address RR estimation effectively. Signal processing theory is crucial for extracting meaningful respiratory patterns from complex FMCW radar data. Physiological principles of respiration guide the interpretation of these patterns and support the development of effective feature extraction techniques. Additionally, machine learning, mainly supervised learning models, is utilized to build predictive models that accurately transform processed radar features into RR estimations [8, 16].

The study underscores the practical implications of the interaction among several critical variables: the raw FMCW radar signal, which captures subtle physiological information related to respiration; the dependent variable of RR measured in breaths per minute; and the intervening variables such as signal processing techniques, feature extraction methods, and the selection of a machine learning algorithm. These intervening variables significantly influence the accuracy and reliability of RR estimation derived from radar data.

1.3 Statement of the Problem

The necessity to reevaluate existing RR measurement methods becomes evident as traditional methods often require direct contact with the patient. This contact leads to discomfort that can inhibit continuous monitoring and degrade the accuracy of health assessments. This research explores the potential of 24GHz FMCW radar as a new contactless measurement technology, aiming to achieve accuracy comparable to traditional methods. It explicitly assesses whether this technique can detect subtle chest wall movements associated with respiration and investigates how integrating machine learning regression models can enhance the accuracy and reliability of RR estimations. This study focuses on measuring standard breathing patterns. Future research will aim to handle irregular breathing cases, expanding the applicability of this technology.

1.4 Objective and Hypotheses

This research aims to develop a contactless RR measurement system using 24GHz FMCW radar, advanced signal processing, and machine learning (ML) techniques to enhance measurement accuracy. The primary goal is to demonstrate that this innovative approach can outperform traditional methods in accuracy. The focus will be on the FMCW radar's capability to detect subtle chest wall movements associated with respiration and the potential of ML algorithms to enhance the precision and reliability of RR estimation. This effort will result in the creation of a prototype system and the evaluation of its performance against established respiratory monitoring techniques.

To systematically test the effectiveness of the proposed system, the study sets forth the following premises and hypotheses:

Premises:

1. Combining signal processing techniques with FMCW radar presents a viable and practical approach for estimating contactless RR [3].

2. When applied to analyze radar signals, machine learning methodologies have the potential to identify patterns and correlations that could significantly enhance the precision of RR measurements [16].

Hypotheses:

1. FMCW radar, combined with advanced signal processing, can accurately estimate RR (in breaths per minute) through contactless detection of chest wall movements.

2. Integrating machine learning regression models will significantly improve the accuracy of RR estimation derived from FMCW radar data.

The practical validation of these hypotheses is crucial to this research, exploring the effectiveness and potential applications of 24GHz FMCW radar with advanced signal processing and machine learning for contactless RR measurement. The outcomes of this research are anticipated to significantly contribute to developing more efficient, non-intrusive vital sign monitoring methods in diverse healthcare environments.

1.5 Scope and Delimitation

The necessity to reevaluate existing RR measurement methods becomes evident as traditional methods often require direct contact with the patient. This contact leads to discomfort that can inhibit continuous monitoring and degrade the accuracy of health assessments. This research explores the potential of 24GHz FMCW radar as a new contactless measurement technology to achieve comfort and accuracy comparable to traditional methods. The 24GHz band is utilized because it falls within the Industrial, Scientific, and Medical (ISM) radio bands, which are globally available and designated for non-commercial use, reducing regulatory barriers and interference issues [17]. FMCW radar is preferred due to its superior range resolution and ability to accurately measure small movements, making it highly suitable for detecting subtle chest wall movements associated with respiration.

This study explicitly assesses whether this technique can detect subtle chest wall movements associated with respiration and investigates how integrating machine learning regression models can enhance the accuracy and reliability of RR estimations. This research focuses on measuring standard breathing patterns. Future research will aim to handle irregular breathing cases, expanding the applicability of this technology. By addressing these aspects, this study aims to develop a more efficient, non-intrusive method for respiratory monitoring, which can significantly improve patient comfort and the overall quality of healthcare.

1.6 Significance of the Study

Developing a highly accurate, contactless, patient-centered system for RR measurement has the potential to revolutionize respiratory assessment. This innovative approach aims to enhance clinical decision-making, improve patient outcomes, and raise the quality of care for individuals with respiratory conditions in diverse healthcare settings. This research could significantly impact respiratory monitoring practices by overcoming the significant limitations of existing methods and meeting the changing healthcare demands. Emphasizing patient comfort and hygienic monitoring, this system offers advantages in various scenarios, including managing infectious diseases and providing long-term respiratory care.